ELECTRON CLOUD MODELING CONSIDERATIONS AT CESRTA*

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Abstract

The Cornell Electron Storage Ring (CESR) has recently begun operation as a test accelerator for next generation linear collider damping rings. This program, known as CesrTA, includes a thorough investigation of synchrotron-radiation-generated electron cloud effects. CESR is capable of operating with a variety of bunch patterns and beam currents, as well as with both electron and positron beams. Understanding the buildup of the cloud under these conditions requires the use of well-validated simulation programs. This paper will discuss three such programs; POSINST, ECLOUD and CLOUDLAND, which have been benchmarked against each other in parameter regimes relevant to CesrTA operating conditions, with the aim of understanding systematic differences in the calculations.

INTRODUCTION

The electron cloud effect is a complex phenomenon that requires sophisticated computer simulations to properly understand. Because of differences in the various cloud modeling codes, especially in the handling of secondary electron yield (SEY), one can often get inconsistent predictions for the same apparent set of parameters. To help sort out these differences, a program of code benchmarking was undertaken at Cornell. For the purposes of this paper, “benchmarking” refers specifically to comparisons of the simulation programs with each other, as opposed to comparisons with data.

The goals of this effort were twofold: first, to investigate the source of any disagreements between the codes; and second, to verify that the codes come into agreement when these differences are removed.

METHODOLOGY

The benchmarking effort primary employed three codes: POSINST [1], ECLOUD, and CLOUDLAND [2]. A fourth code, WARP/POSINST, was also used as a cross-check for some cases.

To simplify comparisons, a canonical set of simulation parameters was chosen (Table 1). They were selected to be as simple as possible, while still being close to typical CESR operating conditions. Parameters in bold type apply to every simulation discussed in this paper, and those in italics apply unless otherwise specified.

Figure 1 shows the average cloud density (number of electrons per cubic meter) vs. time for a run done with these parameters, as predicted by the three codes (note that CLOUDLAND only produces output immediately after each bunch passage). Figures 2 and 3 plot the differential energy distribution (wall current per square meter per eV) and azimuthal distribution (wall current per square meter per degree), for electrons incident on the beam pipe wall. For this set of conditions, there is disagreement on the order of 30% in the average density. The energy distribution is strongly peaked at 0 for POSINST, and around 5-10 eV for the other programs. The angular distribution of the electron flux into the wall is also sharply peaked at zero degrees for POSINST.

Table 1: Canonical Simulation Parameters

Parameter	Value
Train Length	10 bunches
Bunch Current	1 mA
Beam Energy	5.3 GeV
Bunch Spacing	14 ns
Chamber Geometry	Circular, radius = 4.5cm
Primary Photon Flux	.62 photons/particle/m
Quantum Efficiency	10 %
Species	*Positrons*
Magnetic Field	*None*
Reflectivity	*20%*
SEY Peak	*2.0*
SEY Peak Energy	*310 eV*

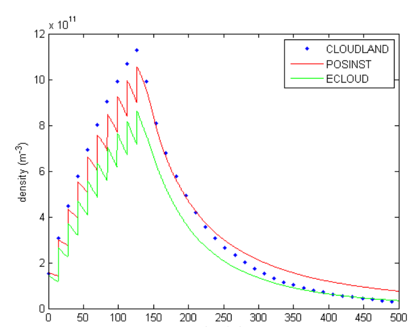

Figure 1: Average density in initial run.

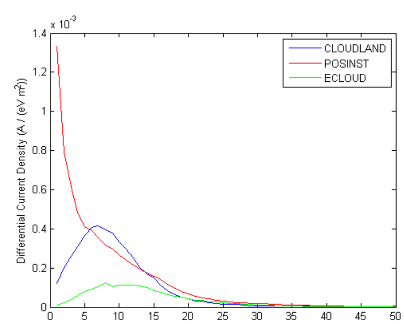

Figure 2: Energy distribution in initial run.

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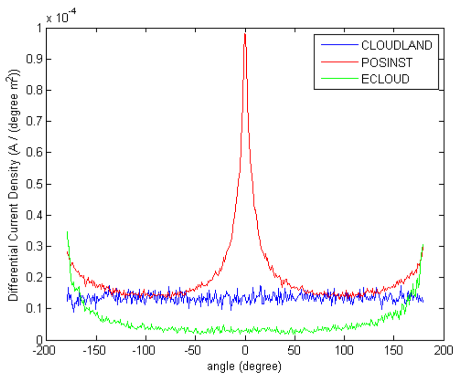

Figure 3: Azimuthal distribution in initial run. The primary photons strike the wall at zero degrees.

PRIMARY EMISSION BENCHMARKING

In order to isolate various sources of discrepancies in the simulation results from each other, it was decided to start with a very simple parameter set, and then to gradually add complexity, benchmarking at each step along the way. The first step towards this end was to remove secondary emission, and investigate directly any differences in the codes' primary emission models. To further simplify things, reflectivity and space charge were both turned off in this "baseline" run.

Not surprisingly, the average density match between the three codes is much better without secondary emission. However, the energy distributions are still somewhat different (Fig. 4). This would lead to a larger discrepancy once SEY is turned back on, since the yield is dependent on incident energy.

One possible source of conflict in the modelling of primary emission is the angular distribution of emitted photoelectrons. For example, the distribution used by POSINST in this run is uniform in solid angle (though this depends on the input parameter *pangphel*), while CLOUDLAND uses a distribution that is more strongly peaked at normal emission. Electrons that are emitted closer to perpendicular will be nearer the center of the pipe during the next bunch passage, and thus receive a higher beam kick. This effect manifests as a somewhat higher energy tail in the CLOUDLAND energy distribution.

To bring the codes into agreement, the same angular distribution (uniform in solid angle) was inserted into each of the codes. The results can be seen in Figure 5; the match is greatly improved.

The next step in the benchmarking effort was to check that this agreement was not broken by reintroducing any of the complications we ignored in the simple case. Specifically, the codes were benchmarked with space charge on, with an electron beam, with 20% reflectivity, and with a 2011 Gauss dipole field. None of these changes significantly affected the match between the codes, with one interesting exception. In a run with space charge turned on (but all other parameters identical to the baseline), the azimuthal distribution of electrons hitting

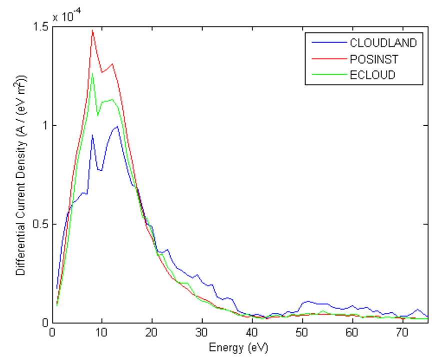

Figure 4: Energy distribution in the baseline run: no SEY, reflectivity, or space charge.

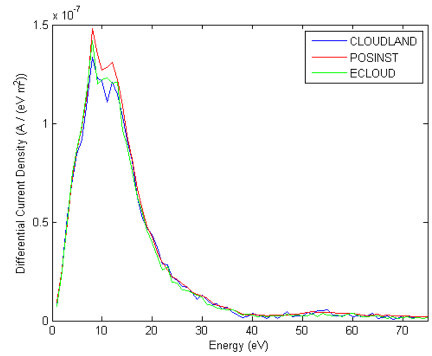

Figure 5: Energy distribution in the baseline run, with primary angular distributions matched.

the beam pipe wall was found to be different for CLOUDLAND than for the other two codes. In particular, the CLOUDLAND angular distribution is much less strongly peaked at zero degrees.

Because CLOUDLAND is the only one of the three programs that models space charge in three dimensions, there was some question of whether it was picking up on some subtlety missed by the 2D codes. To address this question, WARP/POSINST, which is a 3D particle tracking code that uses a POSINST routine to generate secondary electrons [3], was run using the same parameters. Intriguingly, WARP was found to agree with POSINST and ECLOUD, rather than its fellow 3D code CLOUDLAND (Fig. 6). The question of why CLOUDLAND disagrees here is still an open one.

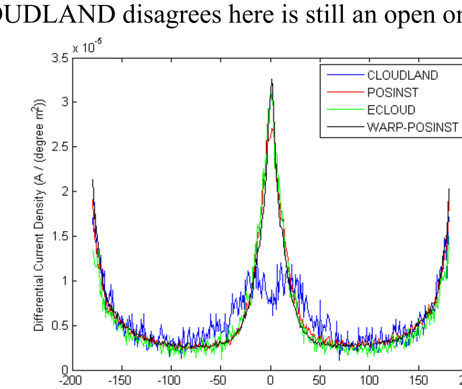

Figure 6: Azimuthal distribution, with space charge.

SECONDARY EMISSION BENCHMARKING

Getting agreement between the codes with secondary emission enabled is more difficult. Although ECLOUD and CLOUDLAND use a similar SEY model, different parameterizations can lead to substantial discrepancies in the results. Of particular importance is the yield at low energy. For a maximum SEY of 2.0 at 310 eV, the yield for normal incidence at 5 eV is .35 in CLOUDLAND and .53 in ECLOUD. Although the two yield curves converge at higher energies, this low energy discrepancy is significant, because most of the cloud electrons have less than 30 eV. The angular dependence of the SEY is also different for the two codes. POSINST has a much more complicated secondary emission model [1], and includes another type of secondary electron (the so-called "rediffused" component). Another key difference is that during secondary emission, POSINST will create new macroparticles with Poisson distributed probability, while ECLOUD and CLOUDLAND always emit a single macroparticle, with charge appropriately adjusted.

To obtain agreement among the three programs, ECLOUD's SEY model was copied into CLOUDLAND and the parameters of POSINST's SEY model were then adjusted to give the best fit to the ECLOUD model. The values of some of these parameters are given in Table 2.

Once these adjustments are made, agreement among the codes is quite good. Figures 7 and 8 show the average density and angular distribution for a run without space charge. For this case the match is essentially perfect in all the metrics used (including the energy distribution, not shown). With space charge, there is still very good agreement between ECLOUD and POSINST, but the azimuthal distribution shows the same type of discrepancy between CLOUDLAND and the other two codes shown in Figure 6. This leads to about a 10% difference in the average density. Runs were also done with an electron beam and with a dipole field. The quality of agreement between the codes was not affected.

Table 2: POSINST Parameters Used to Match ECLOUD

Parameter	Description	Value
P1einf	High Energy Elastic Yield	.020764
P1epk	Peak Elastic Yield	.43144
E0w	Elastic Energy Width	66.3 eV
P1rinf	High Energy Rediffused	0
dtspk	Yield at Peak Energy	2.0
Powts	Power Used in Scaling	1.35
Pangsec	Angular dependence	0

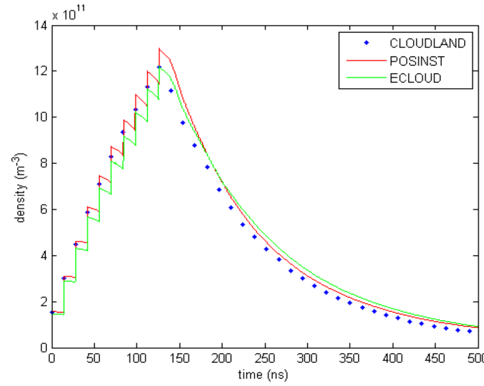

Figure 7: Average density, with SEY but without SC.

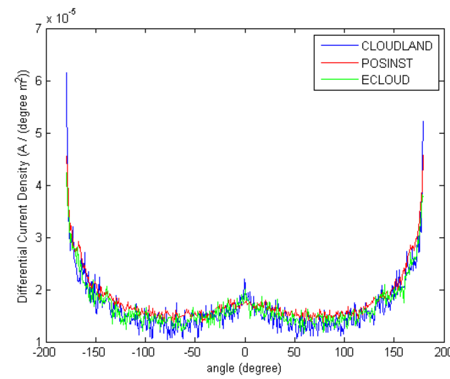

Figure 8: Azimuthal distribution; with SEY but no SC.

CONCLUSIONS

The primary conclusion of this benchmarking effort is that discrepancies in the code results arise from specific differences in the primary and secondary emission models, and that the results can be brought into agreement once these differences are removed. The only exception is the calculation of space charge effects, which appears to be manifestly different in CLOUDLAND.

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